DOCUMENT RESUME

ED 270 318 SE 046 620

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TITLE Children's Conceptions of Light and Color: Understanding the Role of Unseen Rays. Research Series No. 166.

INSTITUTION Michigan State Univ., East Lansing. Inst. for Research on Teaching.

SPONS AGENCY Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE Jan 86
CONTRACT 400-81-0014
NOTE 36p.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Cognitive Development; *Color; *Concept Formation; Elementary Education; *Elementary School Science; *Light; *Misconceptions; Physical Sciences; Science Education; *Science Instruction; *Vision
IDENTIFIERS Science Education Research

ABSTRACT

This study focused on misconceptions related to light and vision. Researchers administered diagnostic tests about light, vision, and color before and after instruction to 227 fifth-grade students over a 2-year period. They also conducted 11 clinical interviews. The tests and interviews revealed that almost all students shared certain misconceptions about light and its role in vision. In particular, most students believed that their eyes perceived objects directly rather than detecting light reflected by those objects. Most students also viewed color as a property of objects, not of light reflected by those objects. When teachers used conventional textbook-based methods of instruction, only a few students were successful in changing these misconceptions. Most students, however, successfully mastered the scientific conceptions when teachers used materials specifically designed to help students overcome their misconceptions. (Author/ML)

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Research Series No. 166

CHILDREN'S CONCEPTIONS OF LIGHT AND COLOR: UNDERSTANDING THE ROLE OF UNSEEN RAYS

Charles W. Anderson and Edward L. Smith

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Charles W. Anderson and Edward L. Smith

Published By

The Institute for Research on Teaching
252 Erickson Hall
Michigan State University
East Lansing, Michigan 48824-1034

January 1986

This work is sponsored in part by the Institute for Research on Teaching, College of Education, Michigan State University. The Institute for Research on Teaching is funded primarily by the Office of Educational Research and Improvement, United States Department of Education. The opinions expressed in this publication do not necessarily reflect the position, policy, or endorsement of the Office or the Department.
(Contract No. 400-81-0014)

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Abstract

Researchers administered diagnostic tests about light, vision, and color before and after instruction to 227 fifth-grade students over a 2-year period. They also conducted 11 clinical interviews. The tests and interviews revealed that almost all students shared certain misconceptions about light and its role in vision. In particular, most students believed that their eyes perceived objects directly rather than detecting light reflected by those objects. Most students also viewed color as a property of objects, not of light reflected by those objects. When teachers used conventional textbook-based methods of instruction, only a few students were successful in changing these misconceptions. Most students, however, successfully mastered the scientific conceptions when teachers used materials specifically designed to help students overcome their misconceptions.

CHILDREN'S CONCEPTIONS OF LIGHT AND COLOR: UNDERSTANDING THE ROLE OF UNSEEN RAYS[1]

Charles W. Anderson and Edward L. Smith[2]

Scientific theories about the world often include entities, such as gravity, genes, or atoms, that are not directly observable. Scientists believe in the existence of these invisible entities because they can be used to explain the behavior of observable objects, such as stones, meter needles, and photographic emulsions.

Children, however, tend to develop theories about the world that are based on their own direct experience and on everyday language. Thus to learn science, they must often acknowledge that their own theories and the evidence of their senses are incorrect or incomplete, and they must accept new theories that depend on unobservable constructs. This is not easy, and many students come to regard science as difficult to learn.

Children's unscientific theories about the world also make science difficult to teach. Most adult scientists and science educators have used the scientific explanations of the world for many years and have forgotten the naive theories they believed as children. Thus teachers and science curriculum developers often work in ignorance of how their students are thinking. Communication difficulties may be exacerbated by the fact that

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[1]Development of this paper was supported in part by the National Science Foundation, grant number SED-8020022. This paper does not necessarily express the official position, policy, or opinions of the National Science Foundation.

[2]Charles W. Anderson and Edward L. Smith coordinate the IRT's Science Teaching Project. Anderson is an assistant professor and Smith is an associate professor of teacher education.

children often use language like that of adults even when their understanding of the world is quite different.

There is a tradition of research on children's naive scientific theories that goes back to the early work of Piaget (1929/1969). The relevance of this body of research to science instruction seems obvious. Its effects on teacher education and the design of science teaching materials have, however, with a few noticable exceptions, been negligible. Teachers, if they are aware of this research at all, generally regard it as an obscure branch of learning theory not directly relevant to their teaching practice. A number of difficulties have prevented this research from being used to its full potential, including the following:

1. In its early stages this research focused on general processes of cognitive development, as exemplified by the work of Piaget. As a result, the theories investigated often were not included in the traditional school science curriculum, making it difficult to apply this research directly to teaching or curriculum development. In recent years, however, a great deal of work has been done on topics of direct relevance for the science curriculum. Examples of these topics include the earth as a cosmic body (Nussbaum & Novick, 1982; Nussbaum & Sharoni-Dagan, 1983; Sneider & Pulos, 1983), problem solving in physics (Larkin, McDermott, Simon, & Simon, 1980; Champagne, Klopfer, & Gunstone 1982), chemical reactions (Ben-Zvi, Eylon, & Silberstein, 1982), genetics (Stewart, 1982), and photosynthesis (Roth, Smith, & Anderson, 1983).

2. The procedures for collecting and analyzing data about student conceptions have generally been extremely time-consuming and labor-intensive. Teachers and curriculum developers, who often operate under great time

pressure, rarely have time to administer clinical interviews, analyze think-aloud protocols of student problem solving, or work through complicated analyses of answers to open response questions. There has been no easy way for the teacher to answer the question, "How do *my* students think about this phenomenon?"

3. Finally, the results of this research have generally been communicated using a variety of specialized jargons in research-oriented journals not readily accessible to practitioners. Thus most practitioners probably have never seen this research reported in a form comprehensible and relevant to them.

This study was designed both to add to the body of research on student conceptions and to investigate ways of making that research useful to practicing teachers.

Objectives

This study reports results of student tests administered during a two-year project that combined research and curriculum development in an effort to improve science instruction (Anderson & Smith, 1983a). The primary objectives of the study are described below.

Describing Students' Conceptions of Light

We wished to describe the conceptions of light, vision, and color held by fifth-grade students. We contrast the student conceptions with the type of understanding expected in a typical fifth-grade science textbook (Blecha, Gega, & Green, 1979). We also compared our results with those of four other studies in which students' conceptions of light were investigated (Andersson & Kaarqvist, 1982; Guesne, 1981; Apelman, Colton, Flexer, & Hawkins, 1983; Stead & Osborne, 1980).

In particular this study focuses on what could be termed *instructionally significant* misconceptions. These misconceptions occupy a middle level with regard to the strength of conviction with which they are held by students. They are not, like the ways of thinking revealed by responses to Piagetian conservation tasks, so deeply embedded in children's world views as to be virtually immune to instruction. Neither, however, are they lightly held or inconsistently exhibited.

Developing Methods of Group Testing and Data Analyses

We also wished to develop procedures for administering group tests and reporting results that are in line with commonly accepted views of what is practical for the purposes of instructional design and evaluation. Thus, we have tried to develop reasonably simple and efficient methods for test administration and data analysis, an easily understandable system for describing the results that is accessable to nonspecialists, and a system for reporting on student conceptions in a summary form that allows evaluation of the knowledge of the class as a whole. Finally, we addressed the issue of whether or not the tests are sufficiently reliable and valid to use for these purposes.

Evaluating the Effects of Instruction

The students whose test responses are described in this paper received one of two types of instruction on the subject of light. During the first year of the study students used *Exploring Science*, a popular fifth-grade science textbook (Blecha, Gega, & Green, 1979). During the second year the textbook was supplemented by a series of transparencies designed to alter

students' misconceptions about light and its effects (Anderson & Smith, 1983b). We used the tests to evaluate the relative effects of these two types of instruction. Demonstrating that different forms of instruction have differential effects on students supports the contention that the misconceptions described here are instructionally significant: neither trivially easy to change nor too deeply held to respond to instruction.

Method

Setting and Student Sample

The primary data source for this 2-year study was a group-administered test given to fifth-grade students before and after they studied a unit on light. In Year 1, the pretest was administered to 102 students and the posttest to 113 students. During Year 2, the pretest was administered to 125 students and the posttest to 136 students. During Year 1, the study included 5 of the 6 fifth-grade classrooms in a small suburban school district (the sixth teacher did not teach the light unit). During the second year, the study included all 6 fifth-grade classrooms in the district. The students were mostly of middle or middle lower class socioeconomic status. They lived in apartment complexes or moderately priced single-family homes. The majority of the students were white, but Afro-Americans, Mexican-Americans, and Orientals were also represented in the sample.

Nature of the Test

We developed the first version of the test on the basis of the propositional content of the *Exploring Science* text. Subsequent revisions of the test were designed to explore the contrasts between the content of the

text and commonly held student beliefs. Project staff members administered a pilot version of the test to one class of students who did not participate in the study. Results were used for test revision, and are not reported in this paper. A second version of the test was used during Year 1. This test, which contained 47 questions, is described in detail in Anderson and Smith (1982). The test was revised again and shortened to 37 questions during Year 2.

The test contains both open-response items calling for drawings or explanations and yes-no and multiple-choice questions. It covers four topics: (a) how people see, (b) the nature of color vision, (c) the interaction of light with various objects (transparent, translucent, and opaque objects; mirrors), and (d) the structure and the functioning of human eyes and their constituent parts. This paper focuses on test results concerning the first two topics.

Project staff administered the test to students in their school classrooms. No attempt was made to make up tests for students who were absent. Students finished the test in 15-35 minutes.

Analysis of Student Responses

The process of using test responses to make statements about student beliefs necessarily involves inference and interpretation. The students themselves were not aware of the existence of alternate theories or belief systems; they were therefore incapable of expressing their own theories in unambiguous language. We tried to develop analysis procedures with inferential processes as unambiguous and open to inspection as possible.

We developed a two-stage analytical procedure. In the first stage student responses were coded using a low-inference system. In the second

stage these coded reponses were used to generate proposition scores representing the nature and the strength of student beliefs.

We distingushed two different types of propositions. *Naive propositions* are beliefs that are inconsistent with commonly held scientific beliefs. *Scientific propositions* are consistent with scientific theory and are derived from the content of the textbook. For example, the naive proposition, "People's eyes see objects in the light," can be contrasted with the scientific proposition, "People's eyes detect light that bounces off of objects." The relationship between coded student responses and proposition scores is described by the following 5-point scoring procedure:

Score	Nature of Response
+2	Response provides a clear statement that student believes in the proposition.
+1	Response allows inference that student believes in the proposition.
0	Response does not provide readily interpretable evidence concerning student's beliefs about the proposition.
-1	Response permits inference contrary to belief in the proposition.
-2	Response is clearly contradictory to the proposition.

Most test items provide information relevant to more than one proposition, and for each proposition, there are several test items that provide relevant information. A microcomputer program was developed to derive proposition scores from coded student responses for each individual student. Statistical analyses across students were done on a main-frame computer.

Thus, three types of data are available: the student responses themselves, the coded responses, and proposition scores representing student beliefs. This paper presents information about students' coded responses, proposition scores, and our inferences about the relationships between them.

Assessing Validity and Reliablility

Maintaining reliablity for the coding procedure was a relatively straightforward process. The coding system was developed by three project staff members working together. Sets of categories were developed, then used independently by the developers on randomly selected tests. When there were disagreements among coders, the coding system was revised or the nature of the categories was clarified.

Intercoder reliablity was also checked after the coding system was completed. All of the student tests were coded by one coder, and a second coder coded a random sample. During the first year there were two questions (out of 47) for which intercoder agreement was less than 80%. Data from those questions were not used. Revisions during the second year further reduced the ambiguity of coding procedures, so intercoder reliability checks were done informally.

Assessing the validity and reliablity of the inferential procedures by which proposition scores were generated from coded student responses was more difficult and problematical. Therefore, two different approaches were used to assess validity and reliability. These approaches are discussed below.

Checking for internal consistency. We assumed that valid student proposition scores should reflect deeply held beliefs unlikely to fluctuate

randomly during the course of a test for most students; therefore, student proposition scores derived from one question should be consistent with proposition scores derived from another. During the development of the coding and scoring systems, proposition scores derived from different items were compared for the sample students. If supposedly similar test items generated contradictory proposition scores, we examined the coding and scoring procedures carefully and often revised them. Similarly, coding procedures were reconsidered if a student had positive scores for both a scientific proposition and the corresponding naive proposition. We used a multitrait, multimethod intercorrelation matrix (Campbell & Fiske, 1959) to check for internal consistency. This matrix indicated that scoring procedures were generally consistent after we made additional changes (Anderson & Smith, 1982).

Clinical interviews. These interviews covered the same topics as the written test, but they gave students a chance to observe phenomena involving light directly and explain them personally to the interviewer. We conducted 11 interviews, 5 before instruction and 6 after. Because each student also took the test, test results and interview results could be compared.

Clinical interview results supported the construct validity of the proposition scores. Student responses to clinical interview questions showed the same patterns of beliefs as the test results. Furthermore, the tests and clinical interviews produced consistent classifications for individual students. Percent agreement for the two instruments for individual propositions ranged from 64% to 100%, with only two propositions showing less than 80% agreement. Data on percent agreement for individual propostions are reported in Tables 4 and 7.

Results

Reporting of results is divided into three sections: students' conceptions of light and seeing, students' beliefs about color and color vision, and the effects of instruction. The first two sections focus on pretest data, the third on posttest data. Since the pretest data are virtually identical for Years 1 and 2, the reporting of pretest data will focus exclusively on Year 2, when both questions and analysis techniques were improved.

Students' Conceptions of Light and Seeing

The scientific conception of vision is presented in the following passage from the *Exploring Science* text:

> Have you ever thrown a rubber ball at something? If you have, you know that when the ball hits most things, it bounces off them. Like a rubber ball, light bounces off most things it hits.
>
> When light travels to something opaque, all the light does not stop. Some of this light bounces off. When light travels to something translucent or transparent, all the light does not pass through. Some of this light bounces off. When light bounces off things and travels to your eyes, you are able to see. (Blecha, Gega, & Green, 1979, p. 154)

Implicit in the scientific conception presented in the textbook are beliefs about the nature of light (that it is constantly in motion), the interaction between light and opaque objects (that light is reflected or bounces off objects), and the functioning of the eyes (human eyes detect reflected light). Our findings indicate that many students have different beliefs.

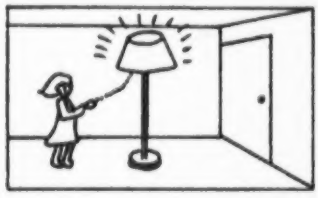
The nature of light. Student responses to one question that addressed the nature and motion of light are presented in Table 1. More than 75% of the

students passed up Option B, which is scientifically correct, in favor of a response that specifies no mechanism at all by which the lamp brightens the room.

Table 1

Student Responses to a Question About the Nature of Light

Question: A girl in a dark room turns on a lamp. What happens then?



	Multiple-Choice Option	Percent of Students (N = 125)
a.	Light comes out of the lamp until it fills the room; then it stops moving (incorrect).	1
b.	Light keeps coming out of the lamp and bouncing off things (correct).	19
c.	The lamp makes the room bright (incomplete).	77
d.	I don't know.	2
	Other	1

Guesne (1981) distinguishes two different misconceptions that might cause children to select Option C over B. First, many children equate light with its source, its effects, or a condition. Second, although some children view light as present in the space between a source and an object, they do not necessarily think of it as being in motion. Guesne also notes that children commonly make distinctions between sunlight, daylight, electric light, and light rays, all of which are regarded as examples of the same phenomenon by physicists.

Further evidence that children, unlike physicists, are not committed to the idea that light is uniformly in motion comes from our clinical interviews. Some students described light as "shining" but not moving. Other students described light as moving only in certain conditions. The following exchange is typical of students in the latter group:

Interviewer: Is there any light in the room right now?

Student: Yes.

Interviewer: Where?

Student: Well, all around.

Interviewer: This light that's in the room now, is it moving?

Student: Yes.

Interviewer: Do you think it's moving everywhere in the room? Up there in corner do you think it's moving?

Student: No.

Interviewer: So you think that there are some places it's moving and someplaces it isn't?

Student: Mhmm.

Interviewer: Where are the places that you think it is moving?

Student: Like right in front of the light bulb. Right out in the middle of the room.

Interviewer: Then it's still around the corners?

Student: Yah.

Although semantic difficulties abound because of the many meanings that the word "light" has in the English language, we believe on the basis of our tests and clinical interviews that most fifth-graders do distinguish between light and its sources or effects. Thus the first of the misconceptions described by Guesne is not a major problem. Most fifth graders believe in the existence of something that pervades a lighted room, including the spaces between objects; however, their beliefs about its nature, and particularly its motion, are often vague and confused.

The interaction between light and opaque objects. The *Exploring Science* textbook portrays both mirrors and ordinary objects as reflecting light, with the difference being that light is scattered by ordinary objects:

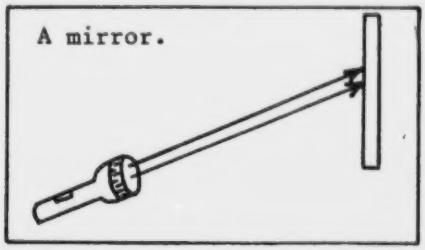
> If the thing you are looking at is smooth and shiny, the light bounces off that thing in the same pattern to your eyes. Then you see an **image**, or picture, of your face. However, if the thing you are looking at is rough and dull, the light scatters so that no image is formed. (Blecha, Gega, & Green, 1979, p.155)

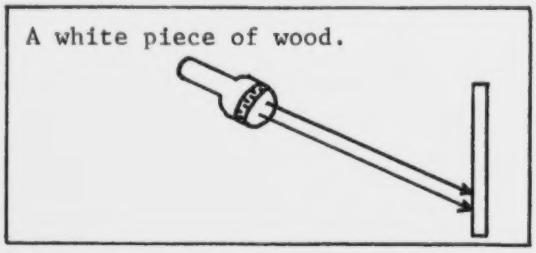
Students commonly understand the interaction between light and objects quite differently. Table 2 summarizes student answers to questions that ask how light interacts with a mirror and with a white piece of wood, respectively.

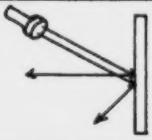
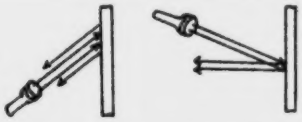
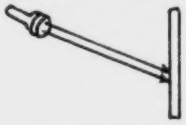
Table 2

Student Answers to Questions About Reflection of Light

Question: Draw arrows on the pictures below to show what would happen to light from the flashlights after it hits the objects below. If you cannot draw arrows, explain what happens in writing.





Description of Category	Typical Student Drawing	Percentage of students (N = 125) Mirror	Wood
Single or double reflected arrows; angle of incedence = angle of reflection (correct for mirror).		47	10
Two or more arrows in different directions (correct for wood).		7	2
Arrows showing reflection at other angles (incorrect).		28	8
Answers showing no arrows away from object (incorrect).		1	60
Other answers, including "I don't know" or no response.		17	18

The results of these and other questions about the interaction between light and opaque objects can be summarized as follows:

1. A few students (less than 20%) never depicted light as bouncing or being reflected off of objects.

2. A majority of the students (over 60%) described light as bouncing off mirrors but not off other objects.

3. About 20% of the students correctly depicted light as bouncing off opaque objects such as a white piece of wood, but only a few of those (2%) correctly portrayed the reflected light as being scattered.

4. Many students who believed that opaque objects reflect light did not view that information as relevant to questions about how people see. The number of students mentioning reflected light in their explanations of vision ranged from 2% to 9%. Other students believed that light merely "shines on" or "brightens" objects that they see.

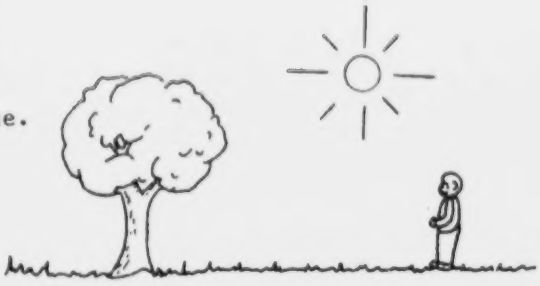
Functioning of eyes. The scientific theory of vision says, contrary to normal language usage, that eyes don't see objects at all. Instead, eyes detect the light that objects reflect. Table 3 summarizing students' responses to a test question in which they were asked to draw arrows showing how light travels so that a boy can see a tree, indicates that few fifth graders shared this belief before the beginning of instruction.

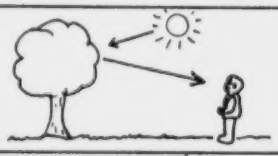
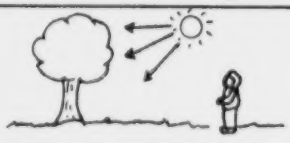
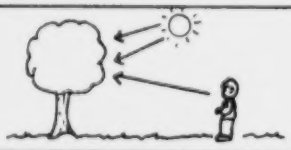
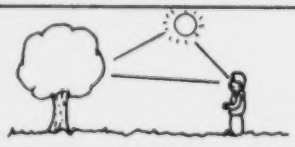
Only 6% of the students correctly drew arrows from the sun to the tree and from the tree to the boy. The majority drew no arrows or lines of any sort between the boy and the tree. These responses are consistent with the interpretation that the function of light is to shine on or brighten the tree, but that it is not directly involved with the act of seeing. There were more students who drew arrows away from the boy's eyes than toward the boys' eyes. These drawings are also consistent with everyday language, when we commonly speak of "looking out" at objects; however, they are inconsistent with the

Table 3

Student Responses to a Question About How People See

Question: This boy sees the tree. Draw arrows to show how the light from the sun helps him to see the tree.



Description of Response	Illustration of Typical Answer	Percentage of students (N=125)
Arrows from sun to tree and from tree to boy (correct).		6
Arrows or lines outward from sun only. No arrows between tree and boy (incorrect).		53
Arrows outward from sun and from boy to tree (incorrect).		11
Line between boy and tree, but no indication of direction (ambiguous).		10
Other incorrect responses.		6
No response or "I don't know."		14

scientific theory. In all of the questions where students were asked to discuss eyes and their role in vision, they tended to describe eyes as looking, seeing, or focusing on objects rather than as receptors of reflected light.

Summary and interpretation. In this section we address the problem of using student response data to make defensible inferences about student beliefs. Since student conceptions are often situation specific, this analysis will focus on data from five test questions, all of which concerned a similar situation: A person looking at an opaque object illuminated by a light source. At least two different interpretations or theories about the situation are possible; each is reasonable, internally consistent, and capable of explaining the observed phenomemon:

1. A scientific interpretation, based on the *Exploring Science* text. Light travels from the source to the object, bounces off, and is detected by the person's eyes.

2. A naive interpretation. Light is a condition created by the light source (but not necessarily in motion). The light brightens or illuminates the object, and people's eyes "focus on" the object itself.

Each interpretation can be broken into propositions or statements about three separate issues: the nature of light, the interaction between light and opaque objects, and the functioning of eyes. Table 4 contrasts these scientific and naive propositions and presents estimates based on pretest data of the percentage of students believing in each proposition.

Two patterns emerge clearly in Table 4. First, less than 10% of the students showed a commitment to any of the scientific propositions. Second, many students are not classified as believers in either scientific or naive conceptions. There are both conceptual and technical reasons for the second

result. At the technical level, the scoring system left students unclassified unless they demonstrated a fairly consistent commitment to a single proposition across all five questions.

Table 4

Naive and Scientific Conceptions of How People See Objects

Issue	Naive Proposition	Percent of Students[a] (N=125)	Scientific Proposition	Percent of Students[a] (N=125)
Nature of light	Light is a condition not in motion (80%)[b]	17	Light is constantly in motion (100%)[b]	8
Interaction between light and objects	Light brightens or illuminates objects (89%)[b]	51	Light bounces or reflects off of objects (90%)[b]	5
Functioning of eyes	Eyes see objects directly (80%)[b]	45	Eyes see reflected light (90%)[b]	6

[a]Percentage of students taking Year 2 pretest who showed consistent commitment to proposition, as shown by proposition score greater than or equal to +2 totaled across five questions about how people see.

[b]Figures in parentheses indicate the percentage of students (n=10) who were classified consistently (as believers or nonbelievers in the proposition) by both tests and clinical interviews. Scores for one student were not used because he changed his mind during the course of the interview.

At the conceptual level it is clear that the three naive propositions presented in Table 4 do not do justice to the full range and complexity of student beliefs about the nature of light, the interaction between light and object, or the functioning of eyes. For example, Hawkins (Apelman et al., 1983) points out that adult learners commonly view light as both a condition, the opposite of darkness, and as "rays" that shine out from discrete light sources. The particular conception or metaphor used depends on the phenomena being observed. Thus the finding that most students do not show a consistent commitment to either scientific or naive propositions about the nature of light is probably correct. Guesne (1981) also describes several aspects of students' naive conceptions that are not accounted for in the statements in Table 4.

Students' Beliefs about Color and Color Vision

The scientific conception of color is presented by the *Exploring Science* textbook in the following passage, which follows a discussion of prisms, spectra, and the colors in white light:

> As stated before, you see the color of things because of the way light bounces off them. Suppose you looked at a car in the sunlight. If the car looked white, all the colors of the sunlight would be bouncing to your eyes. But if the car looked black, none of the colors would be bouncing. All the colors would be "soaked up" by certain things in the paint of the car. These things are called *pigments*. Pigments are found in almost everything on earth. What do you think happens to the light from something that looks red? What happens to the light from something that looks blue? (Blecha, Gega, & Green, 1979, p. 163)

Understanding the passage above obviously requires students to be committed to a scientific conception of how people see. In addition, students must understand ideas about the nature of white light (that it is a

combination of the colors of the spectrum), and about the nature of color (that it is a property of the light reflected to people's eyes). These concepts are contrasted with common student beliefs below.

The nature of white light. One pretest question asked students directly whether white light was a combination of colors of light. The students' responses to this question are summarized in Table 5.

Table 5

Student Responses to a Question About Nature of White Light

Question: Is white light a mixture of colors of light?_____
If you answered "yes," list some of the colors that make up white light.

Description of Response	Percent of students (N=125)
"Yes," followed by "all colors" or listing of colors of spectrum (correct)	2
"Yes," followed by incomplete list of colors in spectrum (partially correct)	3
"Yes," followed by colors not in spectrum or words that are not colors such as "brown" or "flourescent" (incorrect)	8
"No" (incorrect)	72
"I don't know," no response, or other responses	15

A vast majority of the students regarded white light as clear or colorless. Even the data in Table 5 probably overestimate the number of students who have a useful knowledge of the nature of white light. For example, only 1 of the 125 students who took the pretest mentioned the colors in white light in response to a question that asked how white light helps people see a green object.

The nature of color. Everyday language generally describes color as an innate property of objects, as when one says, "The book is red." According to the scientific conception, however, people see reflected light rather than objects themselves. Thus objects appear colored because they have a capacity for differential reflection of different wavelengths (colors) of light. The data presented in Table 6 indicate that few students taking the pretest held this conception.

Table 6

Student Responses to a Question About How Light Helps People See Color

Question: When we see a blue book:

Option Chosen	Percent of students (N=125)
a. The light helps our eyes to see the blue color of the book (incorrect)	61
b. The book reflects blue *color* to our eyes (ambiguous)	22
c. The book reflects blue *light* to our eyes (correct)	8
d. I don't know, other	9

The majority of students chose a distractor consistent with the belief that color is a property of objects rather than of light. The best option was chosen by only 8% of the students. Even this figure probably overestimates the number of students who correctly understood how perceived color depends on the interaction between light and objects. Only 2 of the 125 students described a green book as reflecting green light in their answers to a question about why a book appears green when white light shines on it. Not a single student successfully applied the scientific conception to a more difficult question about the apparent colors of objects viewed in colored light.

Summary and interpretation. Nine questions provided data concerning students' beliefs about color and color vision. As we did with ideas about how people see, we combined and summarized data from these questions through the use of proposition scores, where propositions are statements representing alternate beliefs or interpretations.

The color proposition scores represent alternate interpretations of a commonly occurring event: a person looking at a colored object in white light. Two different interpretations are possible, each reasonable, internally consistent, and capable of explaining the observed phenomenon:

1. A scientific interpretation. White light is a mixture of colors of light. Objects absorb some of those colors of light and reflect others, and people see the colors of the reflected light.

2. A naive interpretation. White light is clear or colorless. It brightens objects and in so doing reveals their colors, which are innate properties of the objects themselves. People's eyes see the colors of the objects.

Table 7 breaks these alternate interpretations down into three separate issues--the nature of white light, the interaction between light and colored

objects, and the nature of color vision--and contrasts naive and scientific propositions for each issue. The same conceptual and technical difficulties exist in generating and interpreting proposition scores as were discussed above in the section on how people see. In this case, however, the level of student commitment to the naive conception seems to be greater, and the level of understanding of the scientific conception clearly is less.

Table 7

Naive and Scientific Conceptions of Color and Color Vision

Issue	Naive Proposition	Percent of Students[a] (N=125)	Scientific Proposition	Percent of Students[a] (N=125)
Nature of white light	White light is clear or colorless (82%)[b]	60	White light is a mixture of colors (73%)[b]	2
Interaction between light and colored objects	Color is an innate property of objects which is revealed by light (64%)[b]	54	Pigments in objects selectively reflect some colors of light (89%)[b]	4
Nature of color vision	People's eyes see colors of objects (89%)[b]	66	People's eyes see colors of reflected light (88%)[b]	2

[a]Percentage of students taking Year 2 pretest who showed a consistent commitment to proposition as indicated by a proposition score greater than or equal to +2 totaled across all relevant questions.

[b]Figures in parentheses indicate the percentage of students (n=11) who were classified consistently (as believers or nonbelievers in the proposition) by both tests and clinical interviews.

The Effects of Instruction

We were especially interested in comparing the effects of two different types of instruction. The teachers in the study taught about light 2 to 3 times a week for 4 to 6 weeks. During the first year the teachers used the textbook and conducted other activities without any interference or help from the research team. During the second year, the teachers were given a set of transparencies accompanied by a teacher's manual explaining the nature of common student misconceptions and how to use the transparencies (Anderson & Smith, 1983b). These transparencies, developed by members of the research team, were designed to address the misconceptions described in this paper.

Rather than comparing total scores that combine a variety of responses into a single number, our comparison of Years 1 and 2 focuses on the scientific proposition scores as parsimonious indicators of student learning that are still descriptive of actual student beliefs. Table 8 presents a comparison of first- and second-year results.

Year 1 and Year 2 proposition scores are less directly comparable than it might seem from the organization of Table 8. Both tests and scoring procedures were modified between years. Proposition scores for Year 2 are based on a larger number of questions, meaning that there was a greater range of possible scores in both positive and negative directions. The wording of some questions was also clarified, and scoring procedures were modified when analysis of Year 1 results revealed inadequacies.

Table 8

Comparison of Scientific Proposition Scores
on Year 1 and Year 2 Posttests

Topic	Proposition	Percent of Students	
		Year 1[a] (*N*=113)	Year 2[a] (*N*=136)
How people see	Light is constantly in motion	28	73
	Light bounces or reflects off	24	79
	People's eyes see reflected light	20	78
Colors and color vision	White light is a mixture of colors	29	52
	Pigments in objects selectively reflect some colors of light	14[b]	29
	People's eyes see colors of reflected light	14[b]	39

[a]Percentage of students who showed a consistent commitment to proposition, as indicated by a total proposition score greater than or equal to +2, totaled across all relevant questions.

[b]Percentages are based on student responses to a single question (#23) and may be unreliable.

The figures given are those we feel represent the most valid constructions of student beliefs. Several alternate methods of scoring were tested, and some of those alternate methods change the figures presented in Table 8 by as much as 15%, generally in the direction of lower percentages for both Year 1 and Year 2. Still, the following generalizations are valid:

1. Instruction produced measurable learning during both years. The differences between pretest and posttest scores were statistically significant even for Year 1 (Anderson & Smith, 1982).

2. Color was much harder for students to understand than basic ideas about seeing. In fact, we believe, on the basis of classroom observation data and interviews with the teachers, that even the teachers did not fully understand the scientific conception of color during the first year. Several of the teachers told us that the transparencies and the manual had helped them to understand color and color vision.

3. The number of students understanding the scientific conceptions of light, color, and color vision was far higher in the second year, when the transparencies and teacher's manual were used, than in the first year. These differences were due not only to the teaching material themselves, but also to a variety of important changes in the behavior of the teachers. A detailed comparison of the classroom behavior of the teachers during the first and second year can be found in Anderson & Smith (1983a).

Discussion

This study had three principal objectives: (a) describing fifth graders' conceptions of light, color, and seeing, (b) developing efficient methods of group testing and data analysis, and (c) assessing the effects of instruction. In this section we consider the degree to which each objective of the study was achieved, discussing implications for research and for practice.

Describing Children's Conceptions

This paper presents descriptions at two theoretical levels. Student responses to test questions are described and discussed, and a more formalized description of alternate conceptions or theories is developed. The answers to the questions are clearly interesting, but some theoretical framework or formalism is necessary to interpret and evaluate student responses.

The framework used for this paper involved constructing naive, alternative conceptions that could be compared with scientific conceptions on a point-by-point basis. This framework is limited in that it implies that children's alternate ways of thinking have many of the same structural properties as mature scientific theories, including internal consistency and the capacity for explaining a variety of observable phenomena. Actual student responses to test questions and student responses to clinical interviews indicate that students' ways of thinking differ from scientific theories with regard to structural properties as well as content. Examples of such differences include the following:

1. Student theories tend to be closely tied to sense experience and to specify causal relationships on a phemonenological level. Scientific theories, on the other hand, are much more likely to invoke invisible mechanisms or entities. Scientists tend to invoke these invisible mechanisms because they are committed to specific theories or to philosophical principles such as the impossiblity of action at a distance or the necessity of conservation of various quantities. Children commonly lack these theoretical and philosophical commitments, so they specify direct cause-effect relationships (e.g., turning on the light makes objects in the room bright) without considering the mechanism that might explain this relationship. Most of the children in the study were clearly so committed to the perception that people see objects directly that a model involving invisible rays did not seem to them to possess additional explanatory power.

2. Children tend to recognize many contextual distinctions that scientists regard as irrelevant. Where scientists see phenomena related by an identical mechanism, children see separate occurrences. For instance, many children recognize that (a) light passes through glass and (b) people can see through glass, but they see no connection between the two facts.

3. Mature scientists, even those whose theories are incorrect, develop theories that exhibit internal coherence and logical consistency. Children are more likely to invoke ad hoc explanations without considering the implications of their explanations for other possible situations.

Thus the method of presenting parallel, alternate conceptions, like other available methods, emphasizes some characteristics of children's thought (in this case internal coherence and conceptual content) at the expense of other characteristics (such as those listed above). The greatest advantage of this mode of presentation lies in its simplicity. It brings out instructionally significant problems in a way that is particularly appropriate for communication with educational practioners or for guiding the process of instructional development. We have used these test results successfully for both purposes.

Developing Methods of Group Testing and Analysis.

In this respect the study was a qualified success. We designed a group-administered test that reveals much about the nature of children's thinking about light; however, the data analysis process was complex and time consuming. We believe that designing such tests is possible, but only if the alternative conceptions are clearly specified in advance. Tests designed, like this one, to help us understand the nature of alternative student conceptions, will have to depend on open-response questions and a laborous, time-consuming analysis process.

Although there are still unsolved problems, we believe that both the testing procedures and the theoretical framework used for this study are superior to more common methods of evaluating student learning. For example, when the number of correct answers to student tests is treated as interval data, the tester makes two implicit assumptions: (a) that learning occurs in incremental bits and (b) that each correct answer represents an equal-sized bit of knowledge. Neither assumption is defensible. Advances in test design

and construction must be associated with the development of better psychological bases for testing.

Assessing the Effects of Instruction

The tests provided data useful for both formative and summative evaluation of instruction. In summative terms, the testing established (a) that instruction was much more effective when teachers used the supplemental materials provided by the research team than when they did not and (b) that learning about how people see was easier for students than learning about color vision. These results also demonstrate the potential power of research on student conceptions for formative evaluation leading to improved instruc-tion. This research provided essential information for the development of an instructional treatment that was highly successful in improving student learning. The potential for improved student learning justifies continued commitment to this research procedure.

References

Anderson, C. W., & Smith, E. L. (1982,April). Children's conceptions of light, color, and seeing: Phase I test results. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Fontana, WI.

Anderson, C.W., & Smith, E.L. (1983a, April). Teacher behavior associated with conceptual learning in science. Paper presented at the annual meeting of the American Educational Research Association, Montreal.

Anderson, C. W., & Smith, E. L. (1983b). Transparencies on light: Teachers' manual (Research Series No. 130). East Lansing: Michigan State University, Institute for Research on Teaching.

Andersson, B. & Kaarqvist, C. (1982). How Swedish pupils, ages 12-15, understand light and its properties. Molndal, Sweden: University of Gothenburg, The EKNA Project.

Apelman, M., Colton, R., Flexer, A., & Hawkins, D. (1983). A report of research on critical barriers to the learning and understanding of elementary science (National Science Foundation Contract #SED 80-08581). Boulder, CO: Mountain View Center.

Ben Zvi, R., Eylon, B., & Silberstein, J. (1982). Students vs. chemistry: A study of student conceptions of structure and process. Paper presented at the annual conference of the National Association for Research in Science Teaching, Fontana, WI.

Blecha, M. K., Gega, P. C., & Green, M. (1979). Exploring science: Green book (2nd ed.). River Forest, IL: Laidlaw Brothers.

Campbell, D.T., & Fiske, D.W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. Psychological Bulletin, 56, 81-105.

Champagne, A. B., Klopfer, L. E., & Gunstone, R. F. (1982). Cognitive research and the design of science instruction. Educational Psychologist, 17 (1), 31-53.

Guesne, E. (1981). Children's ideas about light. Unpublished manuscript.

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Models of competence in solving physics problems. Cognitive Science, 4, 317-345.

Nussbaum, J., & Novick, S. (1982). Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy. Instructional Science, 11(3), 183-200.

Nussbaum, J., & Sharoni-Dagan, N. (1983). Changes in second grade children's preconceptions about the earth as a cosmic body resulting from a short series of audio-tutorial lessons. Science Education, 67(1), 99-114.

Piaget, J. The child's conception of the world. (1969) Totowa, NJ: Littlefield, Adams & Co.) (Original work published 1929)

Roth, K. J., Smith, E. L., & Anderson, C. W. (1983, April). Students' conceptions of photosynthesis and food for plants. Paper presented at the annual meeting of the American Educational Research Association, Montreal.

Slinger, L. A., Anderson, C. W., & Smith, E. L. (1983). Studying light in the fifth grade: A case study of text-based science teaching (Research Series No. 129). East Lansing: Michigan State University, Institute for Research on Teaching.

Sneider, C., & Pulos, S. (1983). Children's cosmographies: Understanding the Earth's shape and gravity. Science Education, 67(2), 205-221.

Stead, B. F., & Osborne, R. J. (1980) Exploring students' concepts of light. The Australian Science Teachers' Journal, 26 (3), 84-90.

Stewart, J. H. (1982). Difficulties experienced by high school students when learning basic Mendelian genetics. The American Biology Teacher, 44(2), 80-89.